INTERNET DOCUMENT INFORMATION FORM

A . Report Title: Milestones in the History of Hydrogen Bomb Construction in the Soviet Union and the United States

B. DATE Report Downloaded From the Internet 2/26 /98

C. Report's Point of Contact: (Name, Organization, Address, Office Symbol, & Ph #): American Institute of Physics

D. Currently Applicable Classification Level: Unclassified

E. Distribution Statement A: Approved for Public Release

F. The foregoing information was compiled and provided by: DTIC-OCA, Initials: VM **Preparation Date**: 2/26/98

The foregoing information should exactly correspond to the Title, Report Number, and the Date on the accompanying report document. If there are mismatches, or other questions, contact the above OCA Representative for resolution.

Thermonuclear Milestones ("unedited")

The articles by German A. Goncharov appearing in Physics Today, *November 1996, on pages 44-61 were adapted from this translation. The translation from the original Russian was done by James Wood. Corrections made (by Goncharov or in consultation with Goncharov) in the course of preparing the print version of this article have been incorporated here. Some are indicated in square brackets.*

Contents

[Back to contents]

Milestones in the History of Hydrogen Bomb Construction in the Soviet Union and the United States

By German A. Goncharov

Russian Federal Nuclear Center---All-Russian Scientific-Research Institute of Experimental Physics (RFYaTs-VNIIÉF)

Introduction

The building of atomic, and later thermonuclear, weapons was an event of such epochal significance in the twentieth century that its history has preoccupied scientists worldwide and the international community at large. Those who have participated directly in projects aimed at creating the nuclear arsenal do not, and cannot, remain aloof from exposing the facts of that history. Of special interest is the history of the development of thermonuclear weapons in the United States of America and the Union of Soviet Socialist Republics as the world's first countries to create this most dreadful species of nuclear weapon.

The present article comprises a brief survey and analysis of the principal events that make up the history of the first thermonuclear devices and bombs in the United States and the Soviet Union. The survey covers the period from 1941 through 1956. The sources of information on United States' participation are papers, articles, and books published by American authors in that country. The primary sources on the nuclear history of the Soviet Union are original documentary materials. The referral to documentary sources and the comparison of contemporaneous events in the Soviet Union, the USA and other countries provides the means for working out the interrelationship of events, for piecing together a total picture of the dramatic if tacit competition between the Soviet Union and the United States to discover the principles underlying the construction of a thermonuclear weapon, and for obtaining answers to the many important questions associated with the history of thermonuclear weapons in the Soviet Union. Among those questions: What directly stimulated the first inquiry into the possibility of creating a

hydrogen bomb in the Soviet Union? When and under what circumstances did the government of the Soviet Union make the decision to build a thermonuclear bomb? How did the idea of building a thermonuclear bomb first emerge and subsequently evolve? What essentially was known about work being done on the hydrogen bomb in the United States? What real influence did intelligence secrets have on the work of Soviet scientists? What was known in the Soviet Union about hydrogen bomb projects in the United States from the open press? What was so remarkable about the avenue chosen by Soviet scientists toward the development of a thermonuclear bomb, an avenue that enabled them, despite a four-year head start of the United States in initiating a feasibility study of the building of a hydrogen bomb, to attain by 1955 a level matching the current level in the United States (and even surpassing that country in certain engineering aspects of the construction and testing of thermonuclear weapons)?

The survey is based on directly confirmed documents of fact and on judgements about the course of events (particularly events in the United States) drawn either directly or indirectly from the sum-total of existing materials.

Ongoing research has disclosed new details in the pattern of evolution of ideas that culminated in the brilliant scientific and engineering achievements of the United States and the Soviet Union in the development of thermonuclear weapons. Today it is evident that such achievements were based largely on notions and information that already existed in the early phase of research efforts but could be interpreted not to have been cultivated or implemented in good time in either country. It is impossible to concur with this point of view. Scientists of both countries did everything possible to solve the problem facing them, one of the most perplexing problems ever to occur in the history of mankind. The physical processes involved in the detonation of thermonuclear charges were so extraordinarily complex that concepts could develop only through the attainment of a high level of mathematical modeling and comprehension of these subtle physical processes. Several years of concerted effort were required to reach the necessary level in the two countries. From today's perspective one can only marvel at the spectacular rate of progress achieved in thermonuclear developments in those long-past---but never to be forgotten by those who took part---years when the events described here took place.

[Back to contents]

Brief survey and analysis of key historical events in the making of the hydrogen bomb in the Soviet Union and the United States

[The American program]

The history of thermonuclear research traces its roots back to the year 1941. In a lecture delivered in May of 1941, a Japanese scientist at the University of Kyoto, Tokutaro Hagiwara, postulated the feasibility of triggering a thermonuclear reaction between hydrogen atoms by the explosive fission chain reaction of uranium-235. In September of 1941 Enrico Fermi at Columbia University proposed a similar idea to Edward Teller. Discussions between Fermi and Teller ultimately suggested the feasibility of utilizing an atomic explosion to initiate thermonuclear reactions in a deuterium medium. The conversations with Fermi sparked in Teller a decade-long messianic obsession with the notion of building a thermonuclear superbomb.

In the summer of 1942 a team of brilliant American and European scientists, having assembled in Berkeley, California, to discuss plans for the future of the Los Alamos Laboratory, broached the subject of a deuterium superbomb in the course of their deliberations. On that occasion Edward Teller set forth the first considerations that would become the basis of the "classical Super" project. Through the wartime efforts of Los Alamos scientists, by the end of 1945 the classical Super concept had become a cohesive reality. The basis of the concept was the notion that a stream of neutrons emitted from a gun-type primary atomic bomb based on uranium-235 could initiate a nuclear detonation in a long cylinder of liquid deuterium (by way of an intermediate chamber containing a deuterium-tritium, D-T, mixture). We note that the proposition of adding tritium to deuterium to lower the ignition temperature dates back to 1942 and is credited to Emil Konopinski. It was based on unpublished, then-secret data on

D-T reaction cross sections, according to which the rate of this reaction in the essential temperature range is approximately one hundred times the rate of the D-D reaction in one of its channels. We also call attention to the fact that the practicability of the classical Super was tied in with expectations for the possibility of achieving a nonequilibrium combustion regime of a D-T mixture and pure deuterium.

In the spring of 1946, as work was proceeding on the classical Super, a new invention came to light, one that would later be appreciated as an invention of utmost significance. Klaus Fuchs, with the collaboration of John von Neumann, proposed the application of a new initiation system in the classical Super. The system incorporated a secondary core of a liquid D-T mixture, which would be heated, squeezed, and---as a result---ignited by the energy of radiation from a primary atomic bomb. The probable evolution of the ideas leading up to the birth of the revolutionary concept of utilizing radiation energy for compression can be portrayed from materials published in the United States.

Earlier, in 1942, during the course of a discussion of possible ways to construct atomic bombs, Teller had advanced the notion of an autocatalytic atomic bomb design. He suggested that a boron-10 neutron absorber be placed in the interior of the active fissionable material of the bomb. Teller based his thinking on the fact that boron-10 becomes highly compressed during a nuclear explosion when a pressure difference is created by the ionization of substances with different numbers of electrons in the atoms. The absorption of neutrons diminishes as a result of compression, promoting an increase in the criticality and boosting the energy release from the bomb. This was in fact the discovery of the ionization implosion principle. In 1944 von Neumann proposed that the boron-10 in Teller's autocatalytic system be replaced by a D-T mixture, [assuming] that thermonuclear ignition of the D-T mixture should take place as a result of heating and ionization compression under the conditions of an atomic explosion, thereby increasing the number of fissions in the atomic bomb. Von Neumann's proposal was an important step toward the creation of a thermonuclear-boosted atomic bomb. Then in the spring of 1946, while contemplating how to improve the conditions of initiation of the classical Super and looking at the potential of using a gun-type primary atomic bomb boosted by von Neumann's scheme to accomplish this purpose, K. Fuchs came up with the idea of transferring the D-T mixture out of the uranium-235 into a radiation-heated beryllium oxide tamper. He calculated that under such conditions the D-T mixture, as in the original construction, would be subjected to heating and ionization implosion, thereby establishing conditions for its thermonuclear ignition. To confine the radiation within the tamper volume, Fuchs suggested enclosing the system in a radiation-impervious casing. Since the ionization compression of the D-T mixture in the given system is achieved by the communication of radiation from the active zone of the atomic charge into the externally situated thermonuclear fuel containment zone and is induced by this radiation, it constitutes a radiation implosion. Thus was born the radiation implosion principle in the spring of 1946. Klaus Fuchs' design, the first physical scheme to utilize the radiation implosion principle, served as the prototype for the future Teller-Ulam configuration. Fuchs' proposal, truly remarkable in the wealth of ideas that it embodied, was far ahead of its time and the possibilities afforded by mathematical modeling of the most complex physical processes, without which any future elaboration of these ideas would be impossible. It would take another five years in the United States for the enormous conceptual potential of Fuchs' proposal, itself the outgrowth of a proposal by von Neumann, to be fully substantiated. We mention the fact that on May 28, 1946, Fuchs and von Neumann jointly filed a patent application for the invention of a new scheme for the initiator of the classical Super using radiation implosion.

After Fuchs' departure from Los Alamos on June 15, 1946, events proceeded as follows.

At the end of August, 1946, Teller issued a report, in which he proposed a new thermonuclear bomb configuration as an alternative to the classical Super, dubbing his new scheme the "Alarm Clock." The configuration proposed by Teller consisted of alternating spherical layers of fissionable materials and thermonuclear fuel (deuterium, tritium, and possibly their chemical compounds). This system had quite a few potential advantages. Fast neutrons generated in thermonuclear reactions in the thermonuclear fuel layers would trigger fissions in the adjacent layers of separating materials, significantly boosting the energy release. The ionization compression of the thermonuclear fuel in the explosion process would induce substantial compaction of the thermonuclear fuel and a sharp increase in the rate of the thermonuclear reaction. The proposed construction obviated the need to establish a nonequilibrium thermonuclear combustion regime, but it did require a very powerful atomic initiator to trigger it. The

requirements and power demand for the atomic initiator were tremendous, so much so that the Alarm Clock as an alternative to the classical Super was expected to require the generation of megaton or even multimegaton energy release. The attendant large dimensions and weight of the construction made it difficult or, for all practical purposes, ruled out any possibility of compressing it by chemical explosives. Beginning in September of 1946, theoretical investigations of the classical Super and Alarm Clock projects were conducted in parallel programs at Los Alamos. In September, 1947, Teller issued a report, in which he proposed the application of a new thermonuclear fuel in the Alarm Clock: lithium-6 deuteride. The incorporation of lithium-6 in the composition of the thermonuclear fuel was supposed to greatly enhance the production of tritium during explosion and thereby substantially increase the thermonuclear combustion efficiency. At that time, however, the Alarm Clock project did not appear to be gaining ground or to hold much promise. The pace of subsequent work on the Alarm Clock faded in light of almost insurmountable initiation problems. In the years to follow, nonetheless, theoretical studies of the Alarm Clock continued at Los Alamos in conjunction with work on the classical Super.

On January 31, 1950, the President of the United States, Harry Truman, issued a proclamation directing the Atomic Energy Commission to "continue its work on all forms of atomic weapons, including the so-called hydrogen or superbomb." President Truman's public proclamation gave new impetus to feasibility studies of the creation of a hydrogen bomb in the United States. The decision was made to conduct test-site explosion experiments involving thermonuclear reactions in 1951. One such experiment was the testing of the "Item" boosted atomic bomb.

Another planned experiment was the testing of a classical Super model with a binary initiator operating on the radiation implosion principle. This test was code-named "George," and the tested device was called the "Cylinder." The construction of the initiator in this test was based on the construction patented by Fuchs and von Neumann in 1946. The inclusion of the George shot in the 1951 test plan and the preparations for it played an extremely important role in the American thermonuclear program. The fundamental principle of construction of thermonuclear weapons was in fact revealed during the preparations for the George shot in the United States, its most important ideological constituent being the confinement and utilization of radiant energy from a primary atomic bomb to compress and ignite a secondary, physically isolated core containing the thermonuclear fuel.

A pivotal point in the American thermonuclear program was confirmation of the benefits of the George shot and the retention of this test in the 1951 test plan, notwithstanding the negative results obtained in 1950 from theoretical studies of the performance of the classical Super. The conclusion that the classical Super was a failure was inferred from the results of approximate calculations performed in 1950 by Stanislaw M. Ulam, Cornelius Everett, and Enrico Fermi and corroborated at the end of 1950 by von Neumann's computations on the ENIAC digital computer.

However, the discovery of the new principle was not a direct consequence of the work done in preparation for the George shot. A powerful conceptual impetus had to come from another line of investigation. Continuing his previously begun inquiry into the possibility of constructing a two-stage atomic bomb configuration, in which an initial atomic explosion would cause a secondary sphere of fissionable material to implode and detonate, Ulam in January of 1951 discovered a new approach to the solution of the problem of building a thermonuclear bomb. He conceived the idea of using a stream of neutrons generated in the explosion of a primary atomic bomb to compress, by means of special hydrodynamic lenses, a secondary, physically isolated fusion core containing the thermonuclear fuel. He showed that the powerful compression of thermonuclear fuel is feasible in such a construction, enough to induce thermonuclear ignition and detonation. Ulam also proposed an iterative thermonuclear bomb configuration containing a train of thermonuclear units designed to operate on the same principle and to detonate sequentially. Ulam presented his idea to Teller at the end of January, 1951. Teller hesitated at first, then embraced Ulam's proposal with enthusiasm, but soon proposed his own parallel version, an alternative modification of Ulam's and, in the words of the latter, "perhaps more convenient and general." Teller proposed, instead of a stream of neutrons, that radiation emitted from the primary atomic bomb be utilized to generate a shock wave that would compress the secondary thermonuclear core in Ulam's scheme. The physical thermonuclear bomb configuration proposed by Teller was similar in many respects to the physical configuration of the initiator of the devices used in the George shot, but differed from it in that the thermonuclear fuel was not heated by radiation from the primary atomic bomb ("cold"

compression was conducive to greater compaction of the thermonuclear fuel) and the possibility of using a secondary unit of greater volume with a larger mass of thermonuclear fuel.

Bearing in mind the similarity between the new ideas and the earlier ideas of 1946 that took shape in the initiator of the device for the George shot, Teller later maintained that it was a miracle the new superbomb concept had not been proposed earlier. However, this conceptual breakthrough took place only after it was initiated by Ulam.

On March 9, 1951, Ulam and Teller published a joint report, "On Heterocatalytic Detonations I: Hydrodynamic Lenses and Radiation Mirrors," LAMS-1225, in which they set forth the new concept for the construction of a thermonuclear weapon. Born out of the unification of Ulam's and Teller's ideas (which, in turn, emerged from their own earlier notions and those of Enrico Fermi, Emil Konopinski, John von Neumann, and Klaus Fuchs), the new superbomb design was named the Teller-Ulam configuration.

Soon thereafter, on April 4, Teller signed his name to a second report, LAMS-1230, in which he presented the results of additional analytical and theoretical justification of the new superbomb by Frederic de Hoffmann and proposed a new component for it: an initiator of active fissionable material situated in the secondary core right inside the thermonuclear fuel. The object of the initiator was to trigger an initiating atomic detonation in the interior of the compressed thermonuclear fuel. The George shot was performed successfully on May 9, 1951. "The largest fission explosion to date succeeded in igniting the first small thermonuclear flame ever to burn on earth." The test confirmed the theoretical hypotheses of the feasibility of a nonequilibrium combustion regime of a D-T mixture, at least some of which was located outside the fissionable material of the primary atomic bomb. However, being one of the main origins of the discovery of the Teller-Ulam configuration, the George shot had played its leading role well before its actual detonation. The first thermonuclear test in the United States was approximately the fortieth in a series of nuclear tests performed up to that time in the United States.

In June of 1951 Teller and De Hoffmann issued a report on the effectiveness of using lithium-6 deuteride in the new superbomb configuration. The need for the production of lithium-6 deuteride was acknowledged at a conference on the problems of the superbomb, held in Princeton, June 16-17, 1951. However, the organization of large-scale lithium-6 production had never been undertaken in the United States up to that time. This situation was fostered by the 1950 discovery of an alternative to thermonuclear developments, the possibility of using a more sophisticated chemical implosion technique to build a uranium-235 atomic bomb with a TNT equivalent of several hundred kilotons. Work began on the construction of such a bomb in the United States in 1950 and culminated in successful testing on November 16, 1952 (the "King" shot). In view of the alternative possibility that the problem of constructing nuclear weapons with yields of several hundred kilotons could be solved without the use of thermonuclear materials, the position taken in the United States was that only sensible plan was to develop an "Alarm Clock" releasing energy well in excess of one megaton. [But creating such a large bomb of that design was problematic.] This accounts for the delay in proceeding with the production of lithium-6 deuteride. The erection of a plant for the production of highly enriched lithium-6 in the United States did not commence until May of 1952. The plant in Oak Ridge went into full operation in the middle of 1953.

In September of 1951 the decision was made at Los Alamos to develop a thermonuclear device using the new [Teller-Ulam] principle for a full-scale test, code-named "Mike," scheduled for November 1, 1952. Liquid deuterium was chosen as the thermonuclear fuel. Accelerated work on the device, which required major reconfiguration, made it possible to meet the target date. November 1, 1952, was a day of glorious achievement in the American thermonuclear program: the successful completion of the Mike shot. The explosion had a TNT equivalent of ten megatons. A nondeliverable version of the device was constructed. The immediate problem of the United States was then to build a deliverable thermonuclear weapon. The feasibility of creating an effective deliverable weapon would obviously entail the accumulation of a sufficient quantity of lithium-6. It was the spring of 1954 before the minimum required quantity of lithium-6 could be stockpiled.

On March 1, 1954 the United States detonated the first thermonuclear explosion in the new Castle test

series, the "Bravo" shot, which was the most powerful explosion in the history of American nuclear testing. The thermonuclear fuel in this shot was lithium deuteride with a 40% content of the lithium-6 isotope. In other tests of the Castle series it was necessary to make do with lithium deuteride having a relatively low concentration of the lithium-6 isotope (including natural lithium deuteride). All thermonuclear tests of the Castle series were conducted on the ground or from a barge on the ocean. Not until May 21, 1956, did the United States achieve the first airdrop of a thermonuclear bomb (the "Cherokee" shot). The new series of tests, conducted in the period from May through July of 1956, was aimed at further progress in the construction of lighter and more efficient nuclear weapon prototypes designed to operate in various categories of warheads.

[Back to contents]

[The Soviet Program]

In a memo addressed to I. V. Kurchatov and dated September 22, 1945, Ya. I. Frenkel' was the first Soviet scientist to call attention to the fact that "it would be in our best interest to utilize the high, billion-degree, temperatures developed in the explosion of an atomic bomb in application to synthetic reactions (e.g., to produce helium from hydrogen), which are the energy source of stars and which could even further increase the energy released in the explosion of the principal substance (uranium, bismuth, lead)."

Despite the error of estimation of the temperatures generated in an atomic explosion and the fallacy of suggesting the possibility of fission of bismuth and lead nuclei in an atomic explosion, the thought expressed by Frenkel' in the memo is significant as the first documented communication in the Soviet Union as to the feasibility of using a fission atomic bomb to release energy from lighter nuclei. In sending the memo to Kurchatov, of course, Frenkel' could not have known that the recipient already had information about work progressing along this very line in the United States. Such information began to enter the Soviet Union via intelligence channels in 1945. Most of the incoming reports concerning the problem of liberating nuclear energy from lighter elements, i.e., the superbomb problem, were of a cursory informative character. But then in September of 1945 Soviet intelligence came into possession of concrete information that embodied elements of the "classical Super" theory and was characterized by specific features of possible physical plans of the Super. The plan seen as the principal configuration was a combination of a gun-type atomic bomb based on uranium-235 with a beryllium oxide tamper, an intermediate chamber containing a D-T mixture, and a cylinder of liquid deuterium. The document contained data characterizing the D-T reaction cross sections (represented by an approximate equation), along with data on the degree of reduction of the thermonuclear ignition temperature with the addition of small quantities of tritium to the deuterium. Through the acquisition of this material the first data on the unique properties of tritium became known in the Soviet Union three and a half years before they were openly published. Particularly noteworthy among the materials acquired in 1945 about United States superbomb efforts was evidence that the superbomb was not considered to be a thermonuclear (fusion) bomb, but a boosted atomic bomb. The report stated that in this bomb a primary atomic explosion would lead induce the implosion and detonation of a secondary sphere of plutonium-239. The result would be an increase in the efficiency and energy release of the bomb. The document thus addressed a two-stage atomic bomb construction. However, it was devoid of any clues as to how this concept was to be implemented. Needless to say, the very existence and content of the intelligence information were known only to an extremely limited circle of people in the Soviet Union.

The feasibility of constructing a superbomb was announced in the open press in 1945. The *London Times* of October 19, 1945, reported the disclosure by Prof. Marcus Oliphant, speaking in Birmingham the day before (October 18, 1945), that the capability now existed to produce a bomb one hundred times more powerful than the one employed against Japan, in other words, a bomb with a TNT equivalent of two megatons. The report stated that, in Oliphant's opinion, a bomb can be constructed with one thousand times the energy released by existing types.

The reports of the superbomb capability could not help but unnerve the directors of the Soviet atomic project. On October 24, 1945, the superbomb issue was one of several questions that Ya. P. Terletskii,

on orders from Lavrenti P. Beria, was to address to Niels Bohr on his return to Denmark from the United States. There were two meetings between Terletskii and Bohr in Copenhagen in the period of November 14-16, 1945. Bohr's answer to a question about the truth behind the recent report of a superbomb contained the following remark:

> What does it mean, a superbomb? This is either a bomb of a bigger weight than the one that has already been invented, or a bomb which is made of some new substance. Well, the first is possible, but unreasonable, because, I repeat, the destructive power of the bomb is already very great, and the second---I believe---is unreal.

This reply did little to convince the directors of the Soviet atomic project that the reports of superbomb efforts in the United States could be dismissed. However, it helped to solidify the philosophy that the intellectual and material resources of the Soviet Union should be concentrated to the maximum exclusively on the atomic bomb effort in this period.

Nonetheless, Kurchatov recruited Yu. B. Khariton with orders to collaborate with I. I. Gurevich, Ya. B. Zel'dovich, and I. Ya. Pomeranchuk in looking at the possibility of energy release from lighter elements and to present their findings on the matter at a meeting of the Technical Council of the Special Committee. The findings of Gurevich, Zel'dovich, Pomeranchuk, and Khariton were summarized in a report, "Utilization of the Nuclear Energy of the Light Elements," the contents of which were read at a meeting of the Technical Council on December 17, 1945. Zel'dovich was the speaker. The approach to the solution of the problem in the report and in the paper read at the meeting was based on the notion of being able to trigger a nuclear detonation in a deuterium cylinder through the implementation of a nonequilibrium combustion regime. Recently the paper presented at the meeting has been reproduced in full in a recent issue (May 1991) of *Uspekhi Fizicheskii Nauk* (see *Soviet Physics---Uspekhi*, May 1991, page 445). Based on the presentation by Zel'dovich at the meeting of the Technical Council on December 17, 1945, a resolution was passed concerning only measurements of the reaction cross sections of light nuclei, but without any directives as to the organization and pursuit of analytical and theoretical studies or practical work on the superbomb. All the same, in June of 1946 a team of theoreticians at the Institute of Chemical Physics of the Academy of Sciences of the USSR, including A. S. Kompaneets and S. P. D'yakov and under the direction of Ya. B. Zel'dovich, embarked on a theoretical investigation of the feasibility of releasing nuclear energy from light elements as part of the program of research on the problems of nuclear combustion and explosion. Concurrently with the investigations of the Zel'dovich group, intelligence reports of an informative character about United States superbomb activities continued to enter the Soviet Union in the years 1946-47. They were augmented with new public revelations in the open press, including an article by Edward Teller (see *Bulletin of the Atomic Scientists*, February 1947, page 35).